LONG LIFE K-BAND DUPLEXER

Report No. 2

Contract No. DA-36-039-SC-90834

Project No. ARDS-A-142

Second Quarterly Technical Report

1 October 1962 - 1 December 1962

U. S. Army Signal Research
And Development Laboratory
Fort Monmouth, New Jersey

MICROWAVE ASSOCIATES, INC.
BURLINGTON, MASSACHUSETTS

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Signal Corps Technical Requirement No. SCL-5837B

June 6, 1961

Amendment No. 2, April 4, 1962

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MICROWAVE ASSOCIATES, INC.

BURLINGTON, MASSACHUSETTS

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I PURPOSE

The purpose of this contract is to develop a long life K-band three-port duplexer exhibiting extremely low leakage power characteristics. Pertinent desired operation characteristics are as follows:

Frequency	23.5 - 24.5 KMc
Peak Power	100 KW
Pulse Width	0.020 μs
Duty Cycle	.0003
Leakage Power, Spike	.075 ergs
Leakage Power, Flat	40 mw
Recovery Time	0.050 μs
Life	5000 hours
Insertion Loss (low level)	1.0 db max.

In addition, VSWR, and environmental specifications as called for in Signal Corps Technical Requirement SCL - 5837B must be met.

II ABSTRACT

During the second quarterly period of this contract, a specific overall program plan was drawn up to coordinate the various technical activities of concern. In addition, an inspection trip to view an operating ASDE radar was carried out to insure complete compatibility of the duplexer package with that now being used.

In the technical area an improved packaged diode switch was developed and successfully tested at 500 watts peak power. Also, successful initial test results were obtained on several narrow gap ridge waveguide configurations which will be used to mount integrated PN-junction structures.

With respect to other areas of concern, a description of preliminary work performed in the ferrite limiter, gas TR and multipactor areas is presented along with accompanying technical discussions.

III FACTUAL DATA

During the period covered by this quarterly report, efforts were devoted to three areas of concern which are listed as follows:

(a) Organizational aspects of the overall program.

(b) Packaging problems associated with making the duplexer compatible with existing ASDE radar systems for which it is intended; also, general system operational problems which may be associated with this compatibility.

(c) General technical problems in the various areas of concern.

In the following paragraphs, these problems, methods of solution and results achieved to date are presented.

3.1 PROGRAM ORGANIZATION

Because of the various areas of effort required in this program, all four divisions of Microwave Associates are actively participating. These areas involve ferrite, gaseous and semiconductor technology along with a mechanical packaging capability. Therefore, to insure smooth operation of the program, an inter-divisional meeting was held and a general program scheduling plan drawn up. This is shown in Table I. Inspection of this plan shows time scheduling of the various technical areas. Care has been taken to avoid any interruption in the general program provided various technical tasks are completed in their alloted time. Indicated at the end of April 1963, in the technical approach deadline date. At this point in time, all experimental results will be reviewed.

A decision will then be made as to the choice of limiter to be employed in the duplexer. Based on this decision, a final duplexer

TABLE I

SHEET 1 OF 7

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PLAN (5576)

TASK I FERRITE CIRCULATOR AND LIMITER DEVELOPMENT

(A) <u>Ferrite Circulator</u>

Material Investigation

Fabrication of Evaluation Model to Low Level Specs.

High Power Evaluation

Fabrication and Test of Two Final Models Per Final Packaging Spec.

(B) <u>Ferrite Limiter</u>

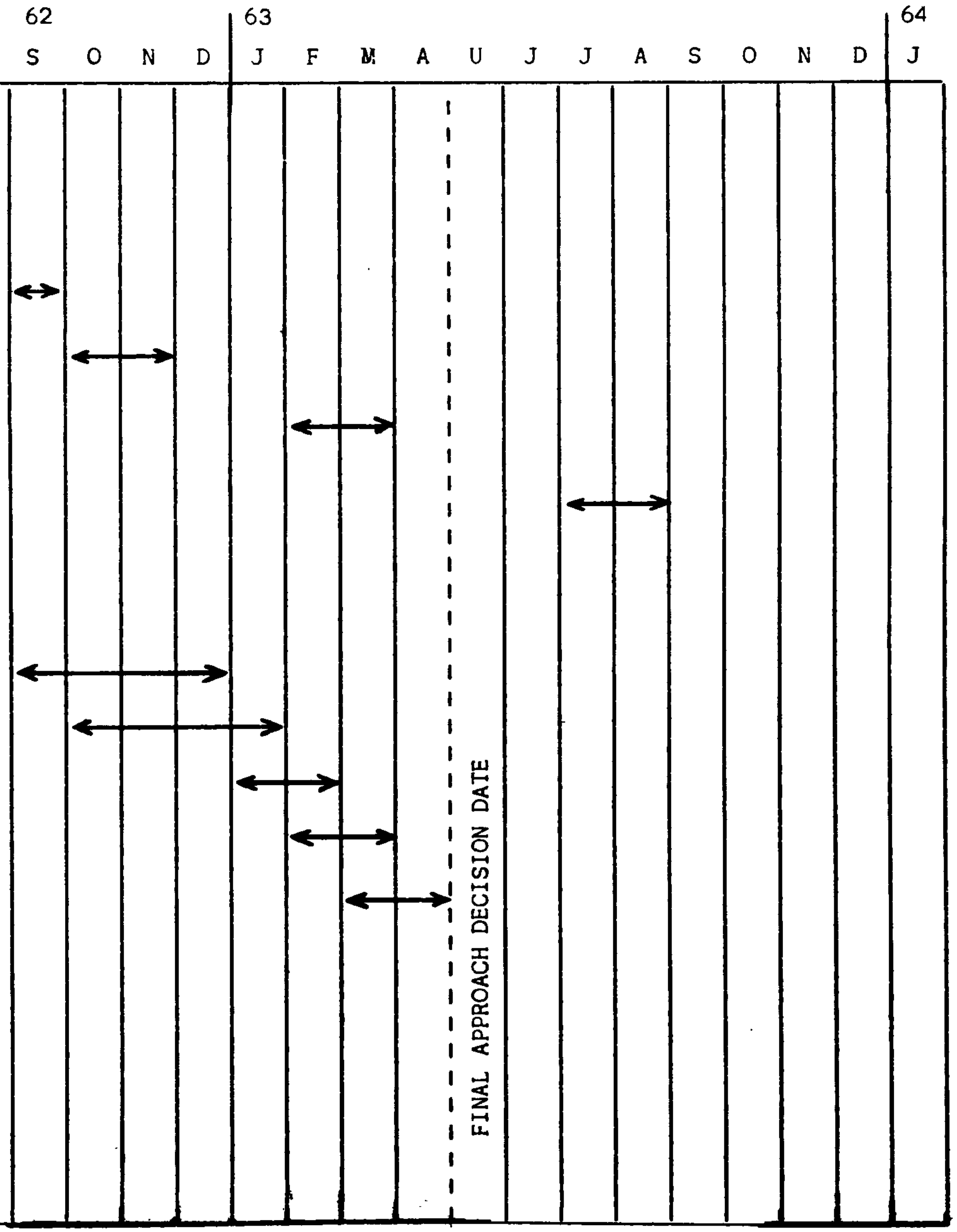
Material Investigation (1)

Fabricate Units and Test

Material Investigation (2)

Fabricate Unit and Test

Ferrite Limiter Final Evaluation



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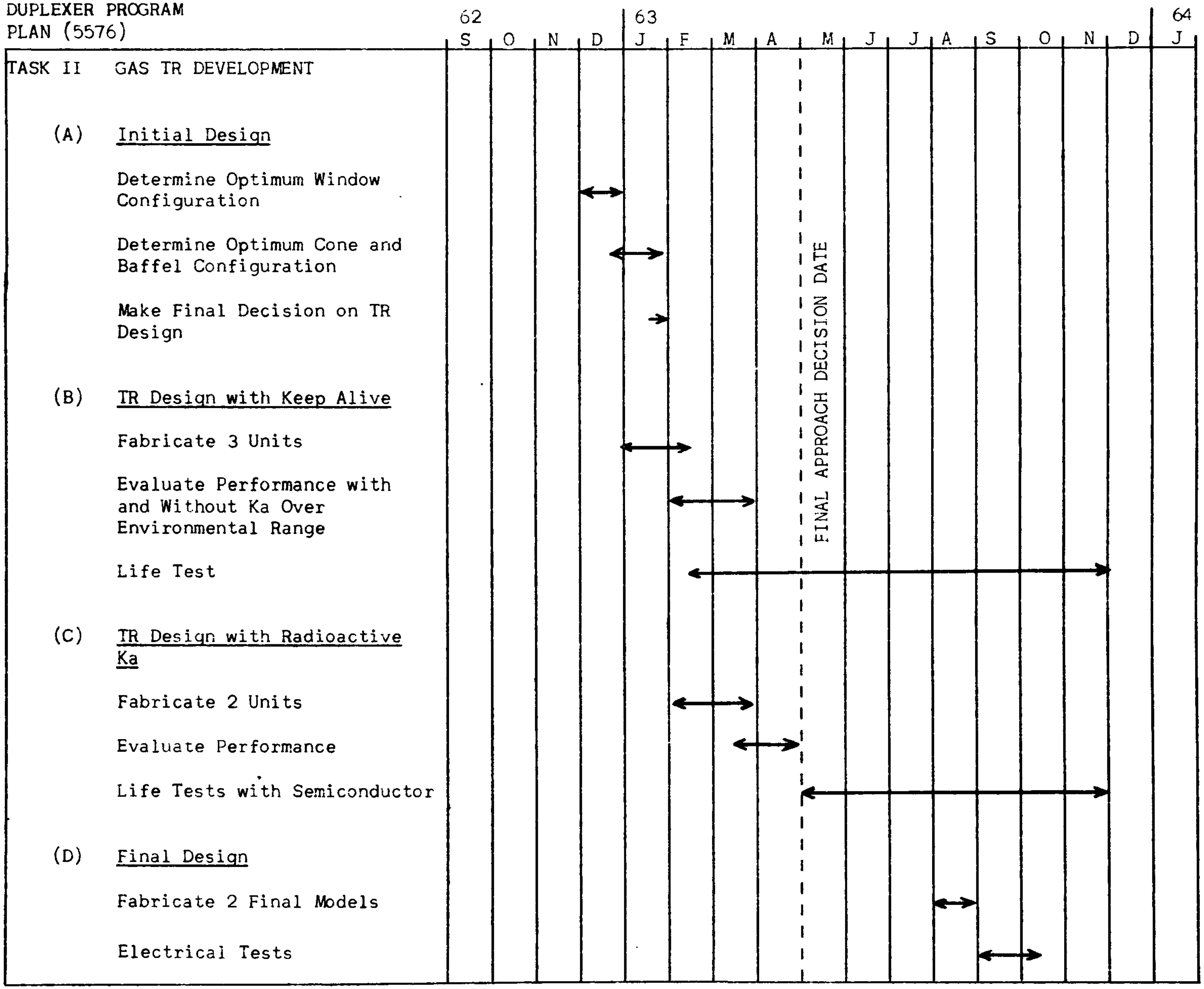

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TASK III MULTIPACTOR DEVELOPMENT

(A) Secondary Emission Material Investigation

Design and Fabricate Test Jigs

Establish Material Processing Techniques

High Power Tests

(B) Multipactor Design

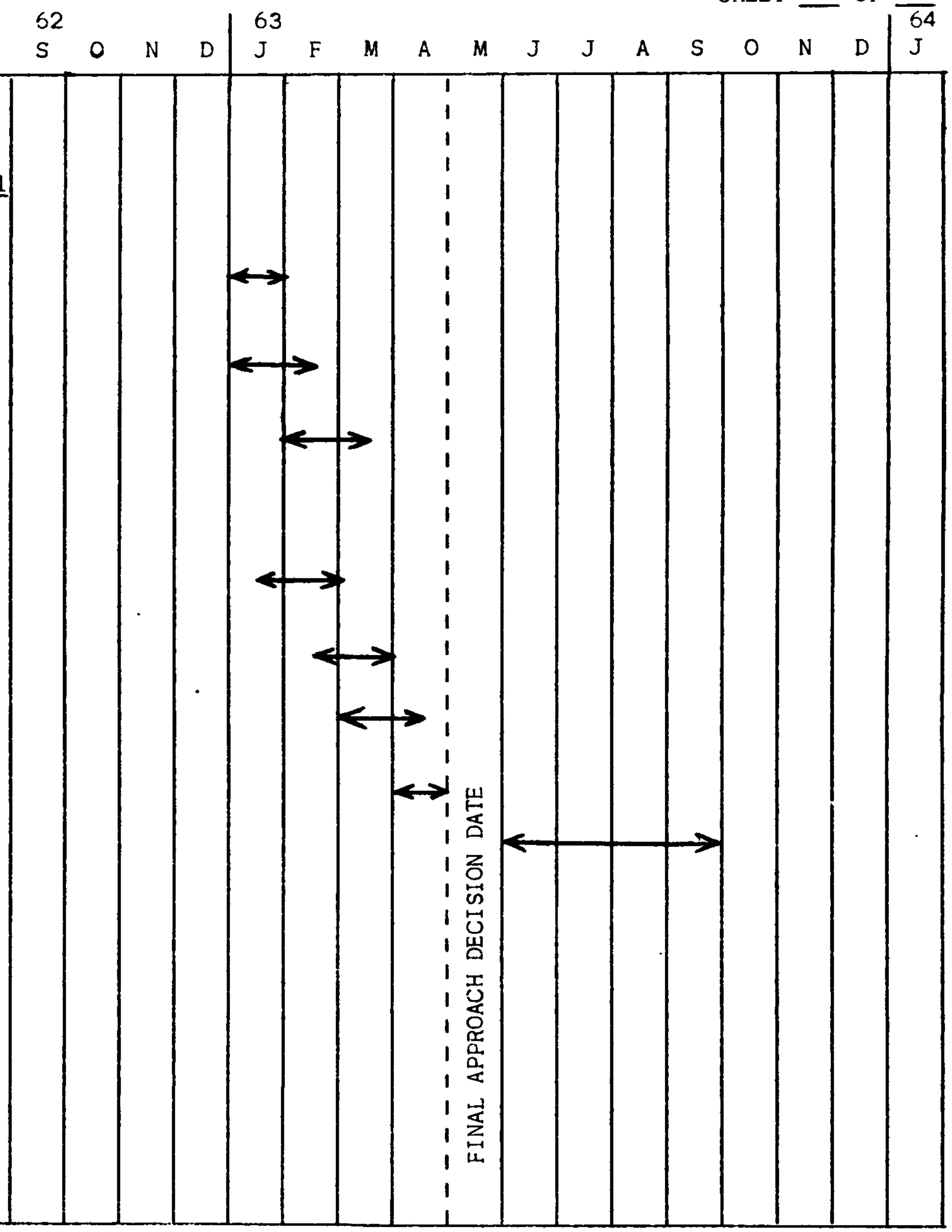
Design and Fabricate 2 Body Structures

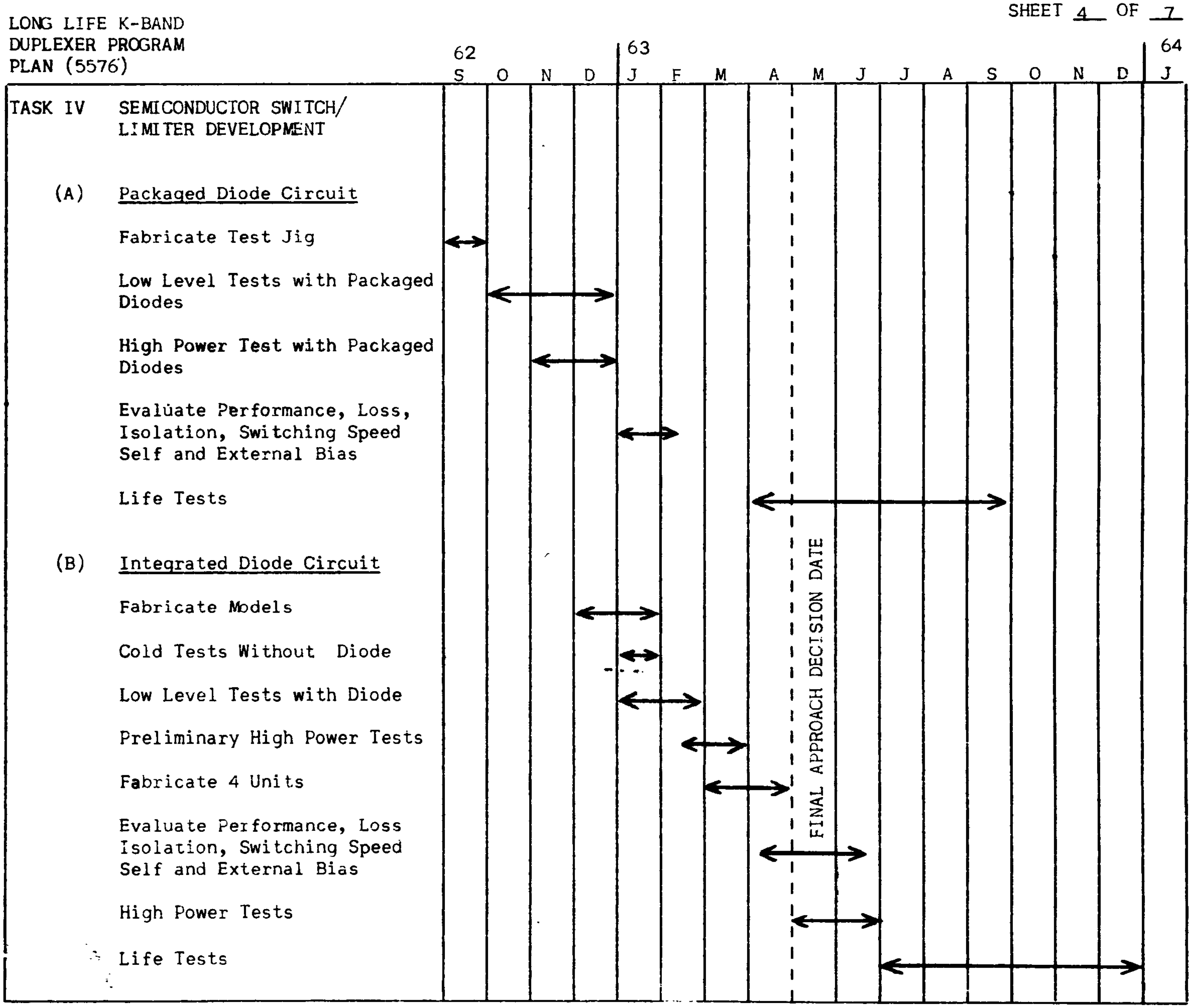
Low Level Tests

Process and Complete Fabrication of 2 Units

High Power Tests

Life Tests

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S O N D J F M A M J J A S O N D J
TASK IV SEMICONDUCTOR SWITCH/ LIMITER DEVELOPMENT
(A) Packaged Diode Circuit
Fabricate Test Jig
Low Level Tests with Packaged Diodes
High Power Test with Packaged Diodes
Evaluate Performance, Loss, Isolation, Switching Speed Self and External Bias
Life Tests
(B) Integrated Diode Circuit
Fabricate Models
Cold Tests Without Diode
Low Level Tests with Diode
Preliminary High Power Tests
Fabricate 4 Units
Evaluate Performance, Loss Isolation, Switching Speed Self and External Bias
High Power Tests
Life Tests
FINAL APPROACH DECISION DATE

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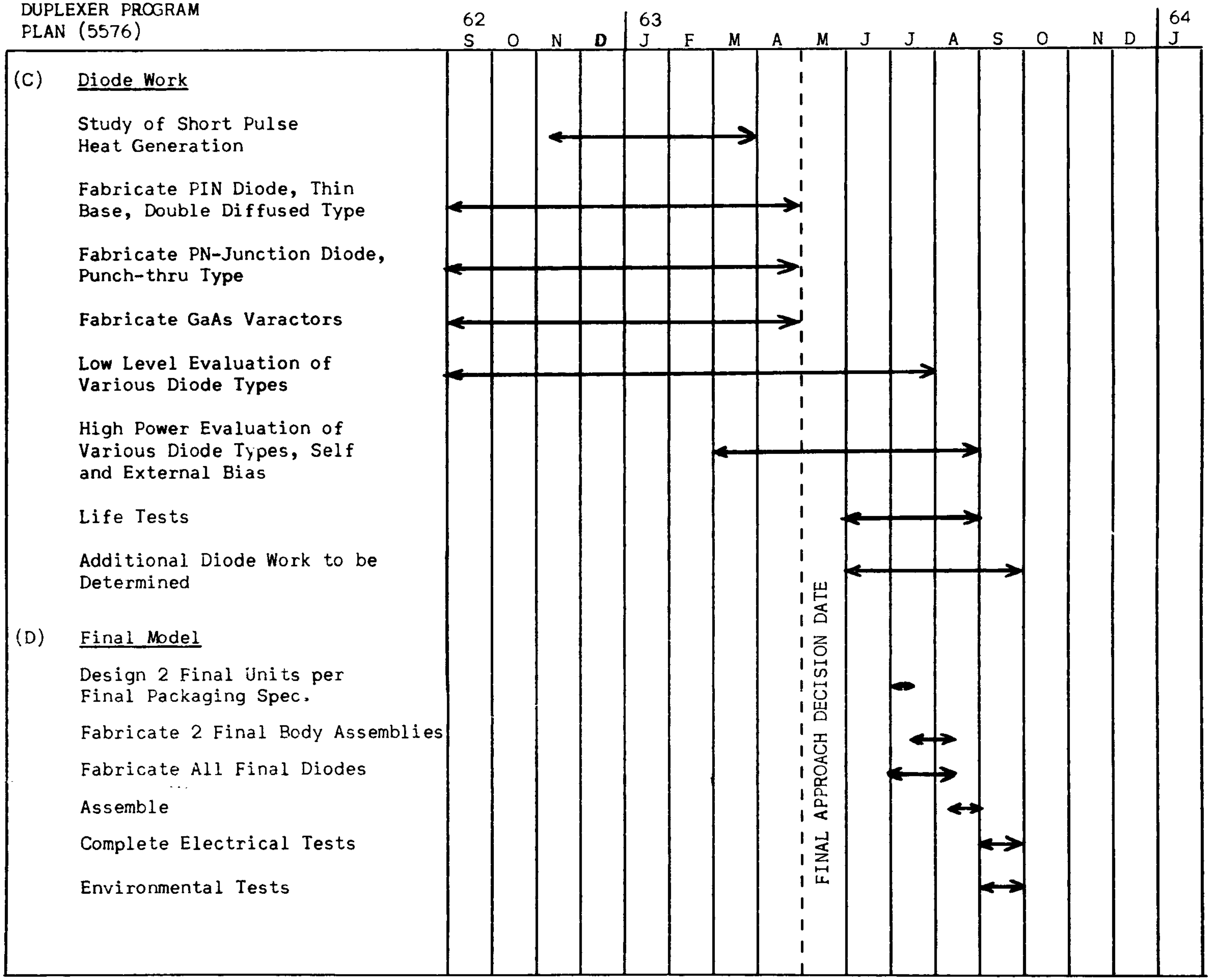
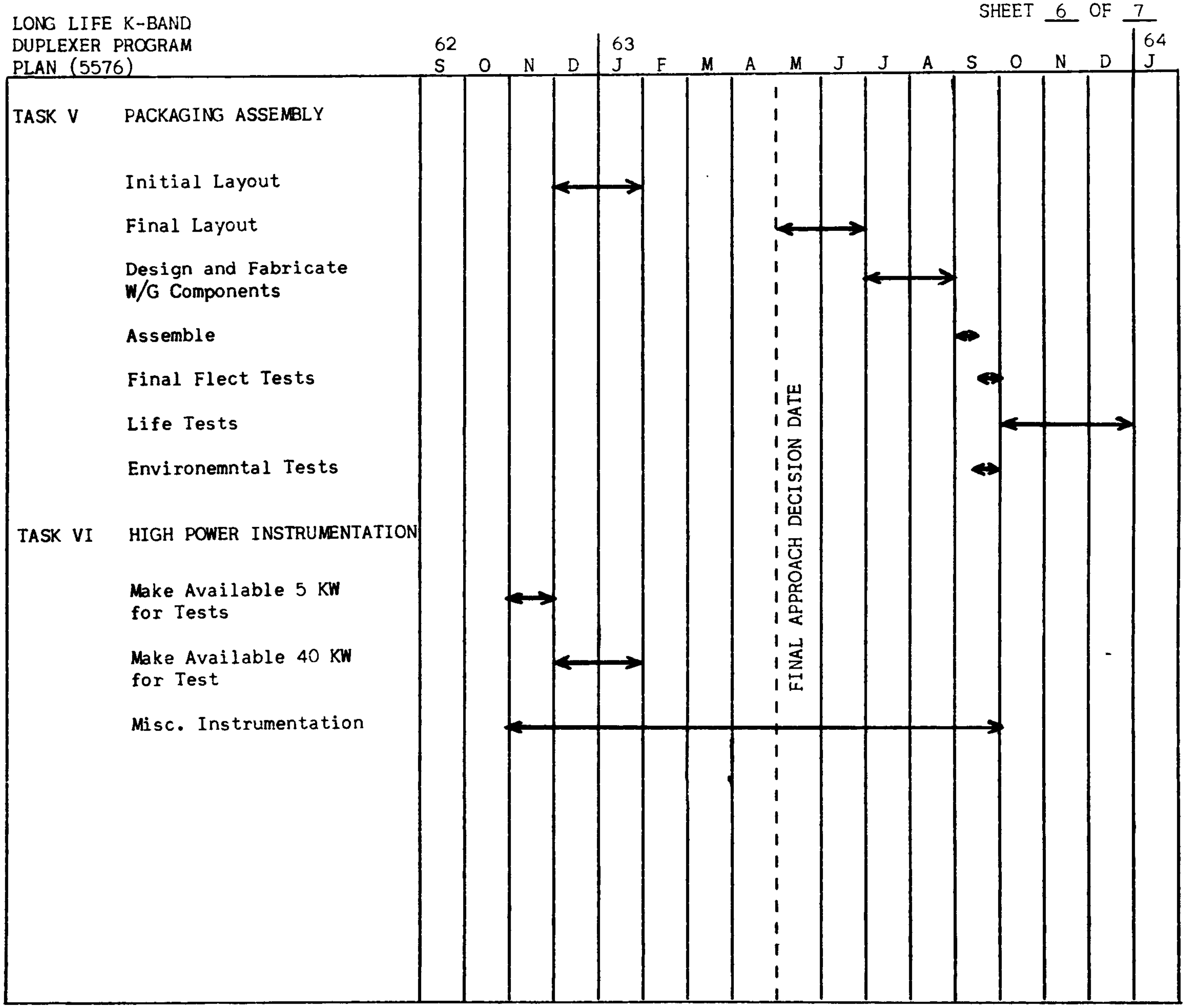
PLAN (5576)

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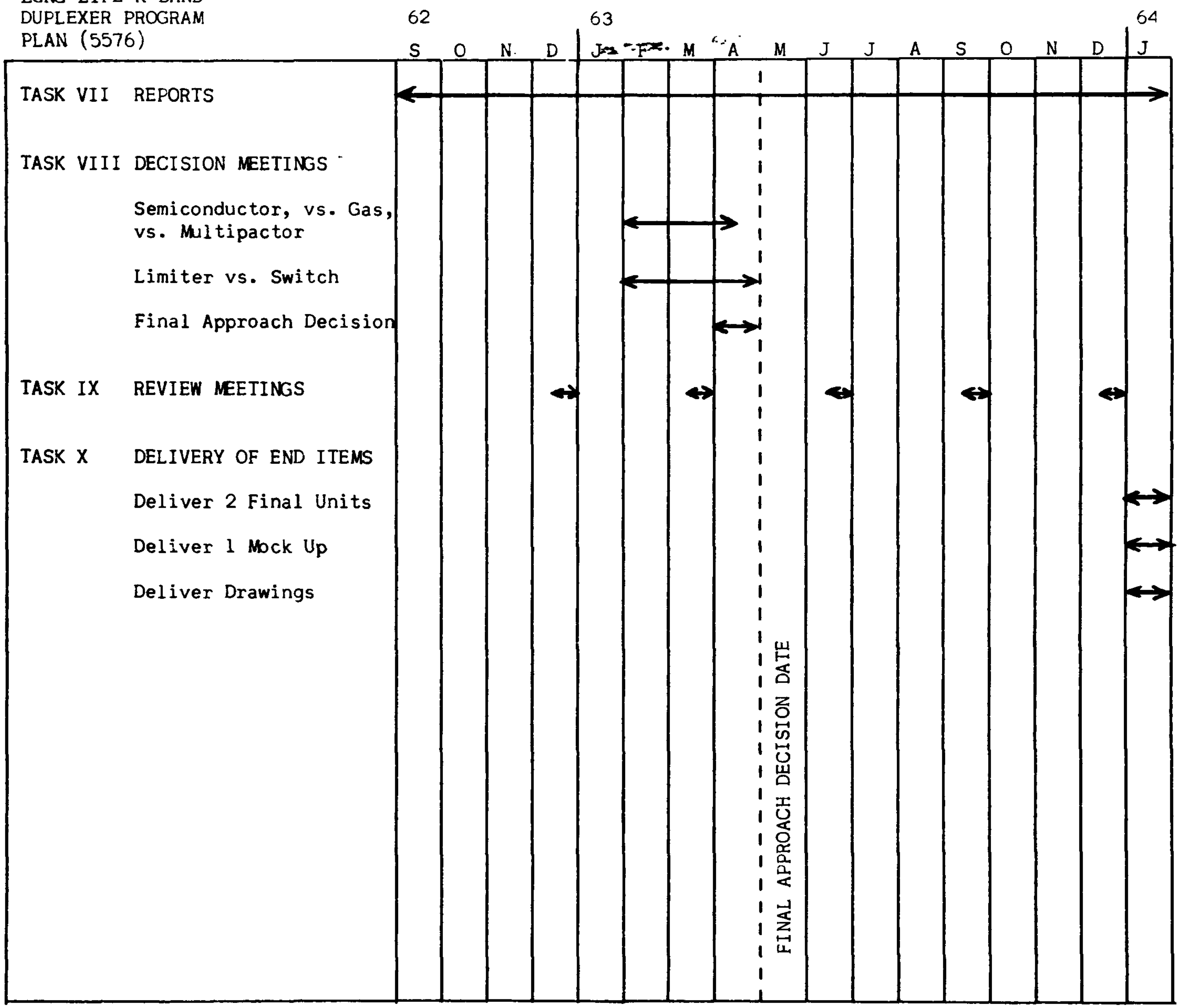
S O N D J F M A M J J A S O N D J
TASK V PACKAGING ASSEMBLY
Initial Layout
Final Layout
Design and Fabricate
W/G Components
Assemble
Final Flect Tests
Life Tests
Environemntal Tests
TASK VI HIGH POWER INSTRUMENTATION
Make Available 5 KW
for Tests
Make Available 40 KW
for Test
Misc. Instrumentation
FINAL APPROACH DECISION DATE

SHEET 7 OF 7

LONG LIFE K-BAND
DUPLEXER PROGRAM
PLAN (5576)



design will be established.

3.2 DUPLEXER PACKAGING AND OPERATIONAL CONSIDERATIONS

In order to insure that the final duplexer design will be interchangeable with existing conventional gaseous TR types, inspection of an operational system was made. This was carried out at Logan Airport, Boston, Massachusetts by several technical representatives of Microwave Associates.

Upon actual inspection of the ASDE radar, it was found that a close physical proximity between the ferrite circulator and magnetron would be necessary. Though undesirable, from a magnetic field interaction viewpoint, it could be tolerated by designing a tightly confined magnetic path for this circulator. In addition, magnetic shielding can be employed. Other than this and a few close tolerance waveguide location dimensions, little difficulty is expected in realizing a compatible duplexer design.

Based on information secured during this inspection, a tentative duplexer package configuration was drawn up and is shown in Figure (1). Waveguide components shaded-in represent existing portions of the radar system to which the duplexer must be physically mated. Space allocation shown for the power limiter following the ferrite circulator is felt to be adequate for any choice of limiter finally selected. No alteration of the existing system is thought to be necessary at this time other than the addition of a mechanical support bracket. Final details concerning this will be established once the final duplexer design is secured.

While conducting this inspection, several system operational characteristics were inquired into. Results of this are tabulated as follows:

(a) A typically good system noise figure is 16 db and may be as high as 25 db before system operation is considered unsatisfactory.

(b) A waveguide run of approximately 17 feet exists between the duplexer and antenna feed.

(c) The system has optional circular polarization provisions which seem to be normally employed.

(d) Minimum location of an operational target is approximately 500 feet. This same condition was found to exist at several other system locations.

During the inspection full cooperation was received from FAA personnel. Information gained from them during the discussion on the system and its general characteristics should help greatly in the overall program effort.

3.3 EXPERIMENTAL RESULTS

During the past quarter, effort was concentrated mainly in the solid-state (PN-junction) limiter area. In addition to this effort, work on other technical areas of concern was started. Results achieved to date are presented in the following sections.

3.3.1 FERRITE CIRCULATOR AND LIMITER EFFORTS

No additional work has been performed on the ferrite circulator since the design described in the previous quarterly progress

report is considered acceptable. However, a small effort has been devoted to the review of available ferrite material which could possibly yield improved circulator performance, especially reduction of insertion loss.

With respect to the investigation of ferrite limiter performance at K-band, a test jig such as illustrated in Figure (2) has been fabricated. Due to the short pulse width of interest, 20 ns, use of most common ferrite material has been ruled out. These would normally yield spike output waveforms greater than 20 ns in width at the power levels of interest. However a Zinc-Y type ferrite[1] holds promise due to its large internal anisotropy field. This characteristic, if present to a sufficiently high degree, will result in an extremely low power threshold of limiting value and narrow spike width at the power level of interest. Samples of this material will be shortly available. Once secured, the samples will be ground to size and tested.

Design characteristics of the limiter configuration in Figure (2) are based on successfully tested units at C and X bands. Reduced height waveguide is employed in the ferrite section to lower the threshold of limiting by virtue of a large RF field intensity for a given power level. Use of a mode suppression has been found necessary to insure good low level loss characteristics. The exact value of required magnetic field will be experimentally determined once tests are started.

1 S. Dixon Jr. "High Power Characteristics of Single Crystal Ferrites With Planar Anisotropy," Journal of Applied Physics, Supplement to Vol. 33, No. 3, March 1962 pp. 1368-1369

3.3.2 SEMICONDUCTOR LIMITER EFFORTS

A considerable amount of work has been performed in the semiconductor limiter area concerned with PN-junction diodes. In the last quarterly report, low level results on a packaged diode switch were presented. This has since been upgraded by use of an improved PIN diode and a slight modification of the microwave test mount. Best results to date are shown in Figure (3). Though insertion loss is slightly above 1.0 db, isolation has been increased to 26 db. This represents a 10 db improvement over the previously described unit.

High power tests were performed on this unit at 24 KMc. A 20 ns RF pulse, as shown in Figure (4), was used with a duty cycle of .0003. Up to 500 w peak, results secured were identical to those obtained under low level conditions; namely, 1.0 db and 17.0 db for insertion loss and isolation respectively. At values greater than 500 w peak, the diode broke down and the isolation dropped to approximately 11 db. No change was noted in insertion loss characteristics up to 750 w. Characteristics of the packaged diode itself are 0.3 pf junction capacitance at 1 Mc and a breakdown voltage value of 500 V.

As mentioned in the previous quarterly report, individual diode power handling capability should be considerably improved when subjected to a very narrow pulse width environment. This aspect is of considerable interest since the pulse width of concern is only 20 ns as compared to typical past history performance of 1 μs minimum. Since diode failure is primarily a function of junction temperature, narrow pulse thermal characteristics are an area worthy of investigation.

The maximum junction temperature of a diode operating

under pulsed RF conditions can be determined by use of the following equation[2] which is valid for the one dimensional heat flow representative of the diodes used.

$$T_{max} = T_o + P_D\theta\sqrt{\frac{t_p}{2\tau_1}} \qquad (1)$$

where T_{max} is the maximum diode junction temperature in ^oC

T_o is the ambient temperature in ^oC

θ is the diode thermal resistance in ^oC/watt from junction to heat sink

P_D is the peak power dissipated by the diode under pulsed conditions

t_p is the applied RF pulse width in seconds

τ_1 is the diode fundamental thermal time constant in seconds.

In equation (1) it is assumed that t_p is less than τ_1 and that the off period is much much longer than τ_1 such that the junction temperature returns to T_o between pulses. In order to illustrate the effect of thermal characteristics on power handling capability, Figure (5) has been prepared. The product $P\theta$ is used as a variable parameter. Assuming a maximum permissible diode junction temperature of 150^oC, one can immediately see the effect of a drastic reduction in t_p if all other parameters are kept constant.

In the previous example illustrated in Figure (3), thermal characteristics of the diode were measured and found to be $32^oC/W$ and 1.5 msec. for θ and τ_1 respectively. In order to secure

2 K. Mortenson "Transistor Junction Temperature as a Function of Times," Proceedings of the IRE, Vol. 45, No. 4, April 1957 pp. 505-506

P_D, an excellent approximation may be made by assuming that the maximum switch isolation value to be due to a pure conductance. This assumption was found to be true* from low level measurements. Once this has been established P_D may be determined by use of equations (2) and (3) given below.

$$\bar{g} \approx 2\sqrt{\overline{1L}_n} \tag{2}$$

$$\%\ P = \frac{400\ \bar{g}}{\bar{g}^2 + 4\bar{g} + 4} \tag{3}$$

where $\bar{g}$ is the normalized shunt conductance

$\overline{1L}_n$ is the high power numerical isolation value

$^o/_o$ P is the per cent of applied power dissipated

Equation (2) is an approximation valid for $\overline{1L}_n$ values greater than 10 and equation (3) is exact. From Figure (3) the value of $1L_n$ (corresponding to 26 db) is found to be 400. This will result in a $\bar{g}$ value of 40 and yield a $^o/o$ P of 9.1 $^o/o$. At 500 w peak input power, a value of 45.5 w is secured for P_D. With this information, T_{max} may now be calculated by use of Equation (1). The resultant value of T_{max}, peak diode junction temperature, is found to be only 34^{o}C for an ambient temperature value of T_o = 30^{o}C. Had a pulse width value of t_p = 1.0 μs been used instead, T_{max} would increase to 57^{o}C.

In addition to the tests made on the packaged diode

*This could be intuitively deduced by the general resonance characteristic of the isolation plot in Figure (3); series resonance occuring at the point of peak isolation.

configuration, additional work was devoted to the realization of a successful integrated ridged waveguide diode mount. The unit mentioned in the previous quarterly report was tested and found to be extremely lossy due to the poor electrical contact of the diode mounting section. As a result, a redesign was made and is shown in Figure (6). The diode, though not shown, is attached to the end of the diode mounting pin. To insure good electrical contact an "in-line" RF choke is formed by the waveguide body and diode mounting pin. Basically, it consists of a very low impedance coax section followed by a high impedance length. Each is made a quarter wavelength long to secure proper choking action.

To date, two forms of this structure have been tested, without diodes, and results are shown for each in Figure (7) with their respective cross sectional configurations. For the larger gap unit, (0.019), insertion loss has a maximum value of 0.25 db and VSWR reaches a value of 1.25 at 24.5 KMc. In the narrower gap unit, (0.004) insertion loss and VSWR maximum values over the required frequency range are 0.5 db and 1.28 respectively. These particular units were made in two halves and then bolted together. They will be soldered in final models which should give a resultant decrease in insertion loss.

The reason for designing several ridged waveguide sections is that the exact height of the diode itself is not yet known. It could possibly vary from .005 to .020 inches when assembled on the end of the diode mounting pin. This depends a great deal on the type of semiconductor construction employed (planar or double diffused), ruggedization techniques employed, and methods used to secure a low

thermal impedance.

3.3.3 LONG LIFE GAS TR TUBE EFFORT

Among the various aspects of work performed under this contract, attention is being given to the more conventional gas TR tube method of limiting power. However, similarity is in name only since the type of TR tube desired will be radically different in several respects; the most important being long operating life in the order of 5000 hours.

A sectional view of the proposed TR tube design is shown in Figure (8). A one piece body construction is utilized to keep solder joints to an an absolute minimum. Material used will be Carpenter #42 alloy which has a coefficient of expansion almost identical to that of kovar. Since the windows employ kovar irises, the possibility of leaks is minimized. These techniques will also allow the tube to be completely hard brazed so that a high bake out temperature may be employed. In addition to securing a high degree of leakage reliability, hard brazing also offers the advantage of lower insertion loss by virtue of the superior RF loss characteristics of the brazing alloy when compared to conventional lower temperature solder. At Ka band, this technique has resulted in insertion loss of a TR design being reduced by a factor of two. In conjunction with this, the tube interior will be chemically treated to reduce gas clean-up to a minimum over the life of the tube.

Electrically, a window Q of approximately 3 will be used with a cone-baffle combination Q of 7 to 8. Spacing between each of the three elements will be 270° at center operating frequency, 24 KMc. Though this approach results in bandwidth reduction when compared to the

more conventional 90° spacing, it enables a greater tube volume to be obtained and thus less susceptibility to gas clean up.

The cone arrangement as shown in Figure (8), has provisions for incorporation of an α or β emitting source to aid in consistent gap firing without a keep alive. Though the leakage spike will probably be greater than if a keep alive were employed, life will be greatly lengthened. The exact type of source which will be most suitable has yet to be established.

3.3.4 MULTIPACTOR LIMITER EFFORTS

In this phase of the program we wish to develop a high power limiter utilizing the multipactor discharge effect as the active medium. In view of the relatively high impedance of the multipactor discharge, when compared to a gas discharge tube, its use as a high power broadband limiter is a most practical application; limiting being accomplished by mismatching and absorbtion effects.

The multipactor limiter has one important characteristic, as will be discussed below, in that it can recover in extremely short time intervals. Another point worthy of mention is that its life depends only upon a good secondary emission surface being retained in a vacuum.

The multipactor discharge, in steady state, consists of a cloud of bunched electrons traveling back and forth between parallel planes in the presence of an applied electric field. The center of gravity of the cloud of electrons must cross the gap in an odd multiple of half cycles of the applied RF field. Therefore, a number of modes exist for a specific gap size. The electron cloud initially develops

as a result of secondary electron emission and in steady state the electron cloud not only regenerates itself, upon impact by secondary emission, but also makes up for those electrons which have become lost. The primary loss mechanism resulting from electrons falling out of phase with the RF field due to space charge effects. Because the electrons must be accelerated across the gap to produce the next bunch, upon impact, it is apparent that the discharge disappears as soon as the RF field drops below its threshold value. Two conditions must be satisfied for the discharge to remain sustained:

(a) The electron energy must be in a range to produce more than one electron upon impact ($\delta > 1$, the secondary emission coefficient). Typically this is in the range of several tens to several thousands of electron volts.

(b) The motion of the center of gravity of the electron cloud must remain in synchronism with the RF field.

An approximate condition for synchronism is

$$V \approx 6.42 \times 10^6 \left(\frac{d}{\lambda}\right)^2 \left(\frac{1}{N}\right) \text{ volts} \qquad (4)$$

where V is the gap voltage

$\frac{d}{\lambda}$ is the ratio of gap length to wavelength

N is the number of half cycles in the mode

A test discharge apparatus is now being fabricated to ascertain discharge parameters and to aid in evaluating secondary emission surface preparation techniques. Figure (9) shows an assembled layout of the complete test setup. It consists of two end pieces which contain vacuum tight windows and a pumping port. The center section is a length of waveguide which

can contain a variety of test discharge structures. Several are shown in Figure (10). The complete assembly is bolted together at the demountable vacuum joints using soft OHFC copper gaskets.

The test structure shown in Figure (10-a) is, roughly speaking, a parallel resonant circuit with extended parallel plane surfaces. This has been purposely done since optimum operation requires that the gap electron field be essentially uniform. The second form of structure in Figure (10-b) consists of a section of low height ridged waveguide matched to the main line by suitable stepped transitions. The reduced height section will be somewhat more than a half wavelength long. By selecting the length of the secondary emitting surface and the size of the discharge volume, the limiting characteristics can be controlled.

With respect to secondary emission material, a silver-magnesium alloy has been ordered and sources are being sought for phosphorous having desirable emission properties. Once these are obtained, an evaluation of surface preparation techniques will be immediately carried out.

IV CONCLUSIONS

An orderly program plan has been set up covering all phases of work concerned with in this contract. Schedules of the various tasks have been so arranged to enable a smooth overall operation with minimum time delay resulting from interdependent operations.

In the semiconductor limiter area, initial, medium power results have been achieved up to 500 W peak on a packaged diode switch configuration. Also, cold tests performed on several ridged waveguide structures indicate they will be quite satisfactory for employment as integrated diode mounts.

With respect to the ferrite limiter, gas TR and multipactor efforts, initial work has been started for the evaluation of these various technical approaches as previously described. Each of these three tasks has been set up as a separate entity, under individual direction to insure that the final, overall evaluation will be secured on an impartial basis.

V PROGRAM FOR NEXT INTERVAL

During the next quarterly report work will be continued on all phases of the contract. A brief description is as follows:

(a) A high power evaluation of the ferrite circulator will be made along with a search for new material capable of yielding superior results.

(b) Low and high power tests will be run on the ferrite limiter along with any required redesign.

(c) The gas TR will be assembled and tested. The effect of α and β sources will be investigated with respect to providing consistent gap firing.

(d) Multipactor designs will be fabricated and tested along with an investigation of processing secondary emission material.

(e) Work will be continued on packaged diode switch assemblies and results evaluated for its employment as a passive limiter. Integrated diode structures will be assembled and tested. In addition, the applicability of various diode designs will be investigated.

VI IDENTIFICATION OF KEY TECHNICAL PERSONNEL

The following key technical personnel contributed to the quarterly period covered by this report.

Name	Title	Hours
Dr. K. Mortenson	Physicist (Director Research & Development)	39
R. Tenenholtz	Microwave Engineer (Group Leader)	139
Dr. R. Damon	Physicist (Director Research & Development)	34
*Dr. M. Gilden	Senior Engineer - Tube Division	8
S. Segal	Microwave Engineer (Group Leader)	58
H. Mooncai	Microwave Engineer	153
*R. Whitney	Engineering Assistant	119
*C. Howell	Semiconductor Engineer	16

*Biographies of these personnel are included in Appendix A. All others have been previously presented.

VII LIST OF ILLUSTRATIONS

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2	K-BAND FERRITE LIMITER ASSEMBLY	4
3	PACKAGED DIODE K-BAND SWITCH PERFORMANCE AT 500 W PEAK INCIDENT POWER	5-6-7
4	DETECTED RF OUTPUT WAVEFORM OF A 6551 MAGNETRON AS VIEWED ON A 0.5 ns RISE TIME OSCILLOSCOPE	5
5	PLOT OF THE DIODE JUNCTION TEMPERATE EXPRESSION	6
6	SMALL GAP RIDGE WAVEGUIDE SECTION	8
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9	DEMOUNTABLE TEST APPARATUS FOR MULTIPACTOR DISCHARGE INVESTIGATION	11
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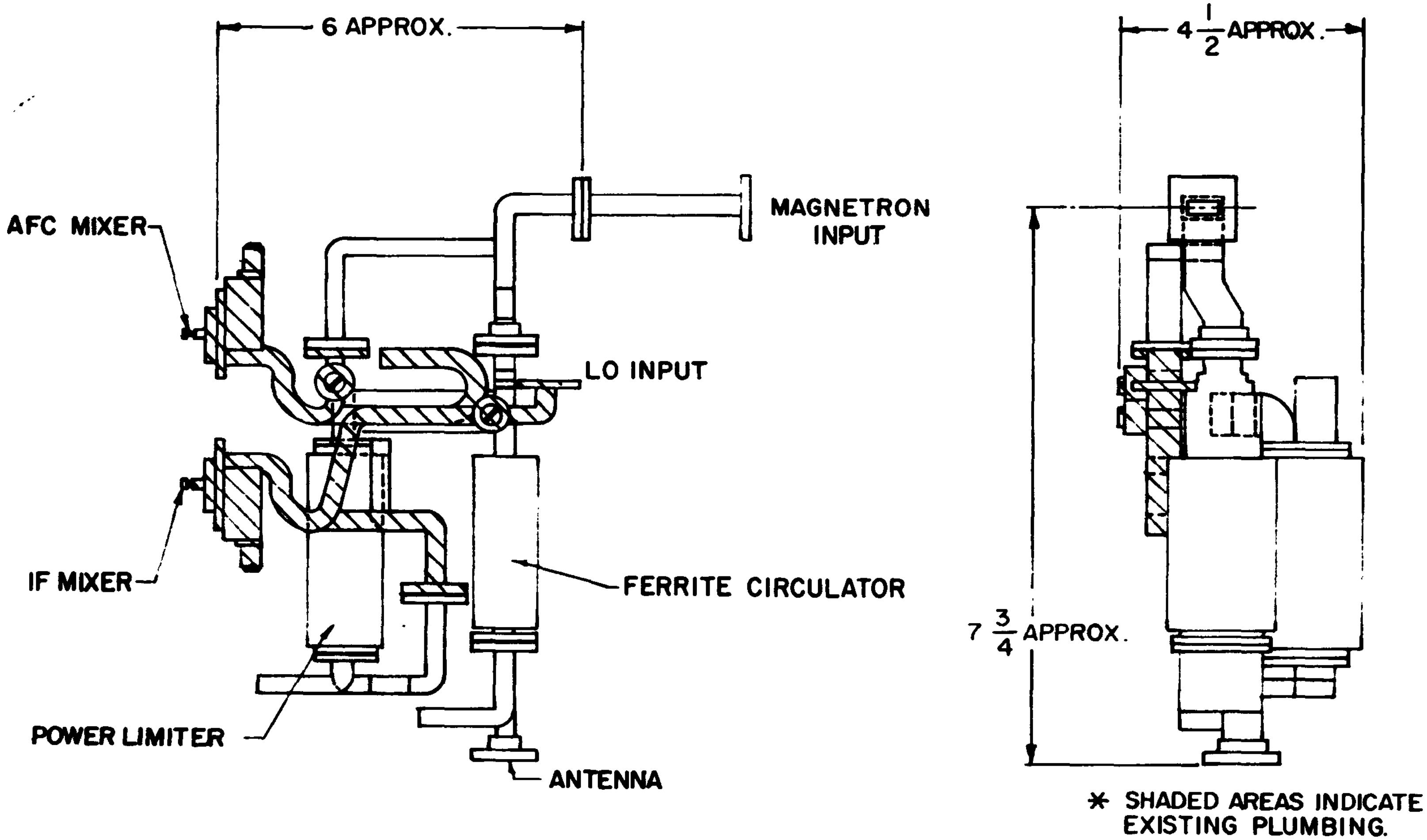


FIGURE 1
TENATIVE DUPLEXER PACKAGE CONFIGURATION

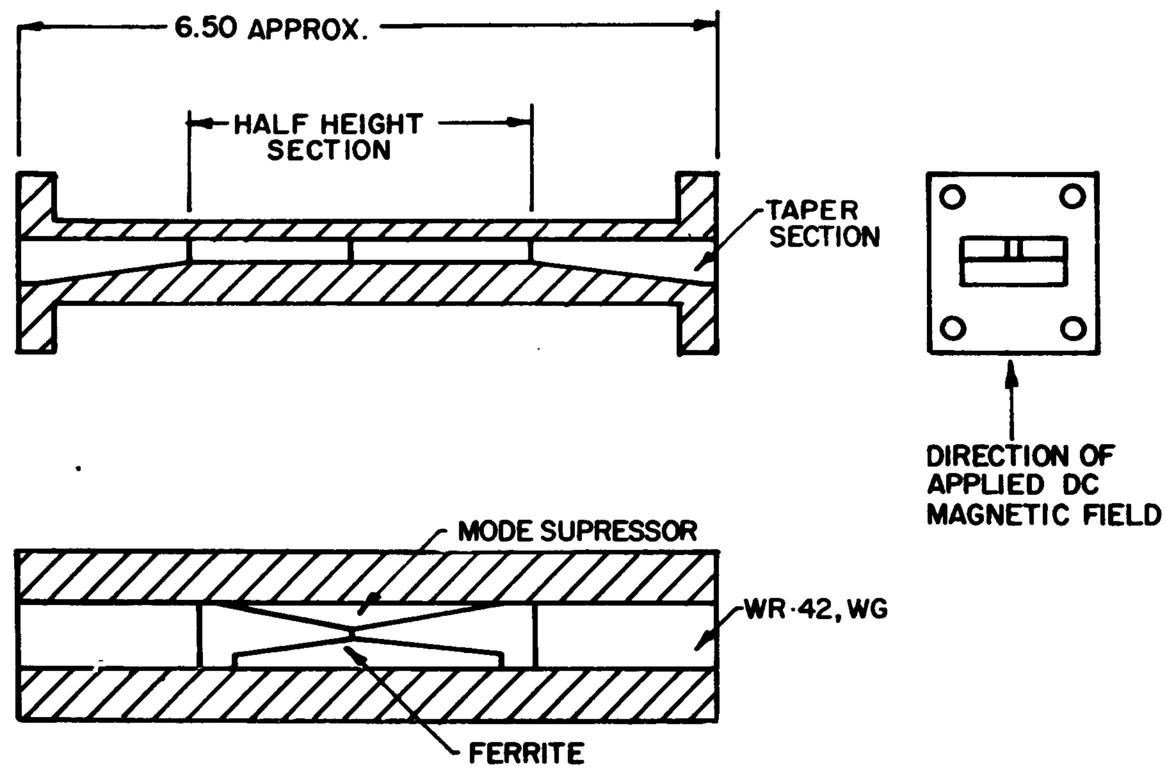


FIGURE 2
K-BAND FERRITE LIMITER ASSEMBLY

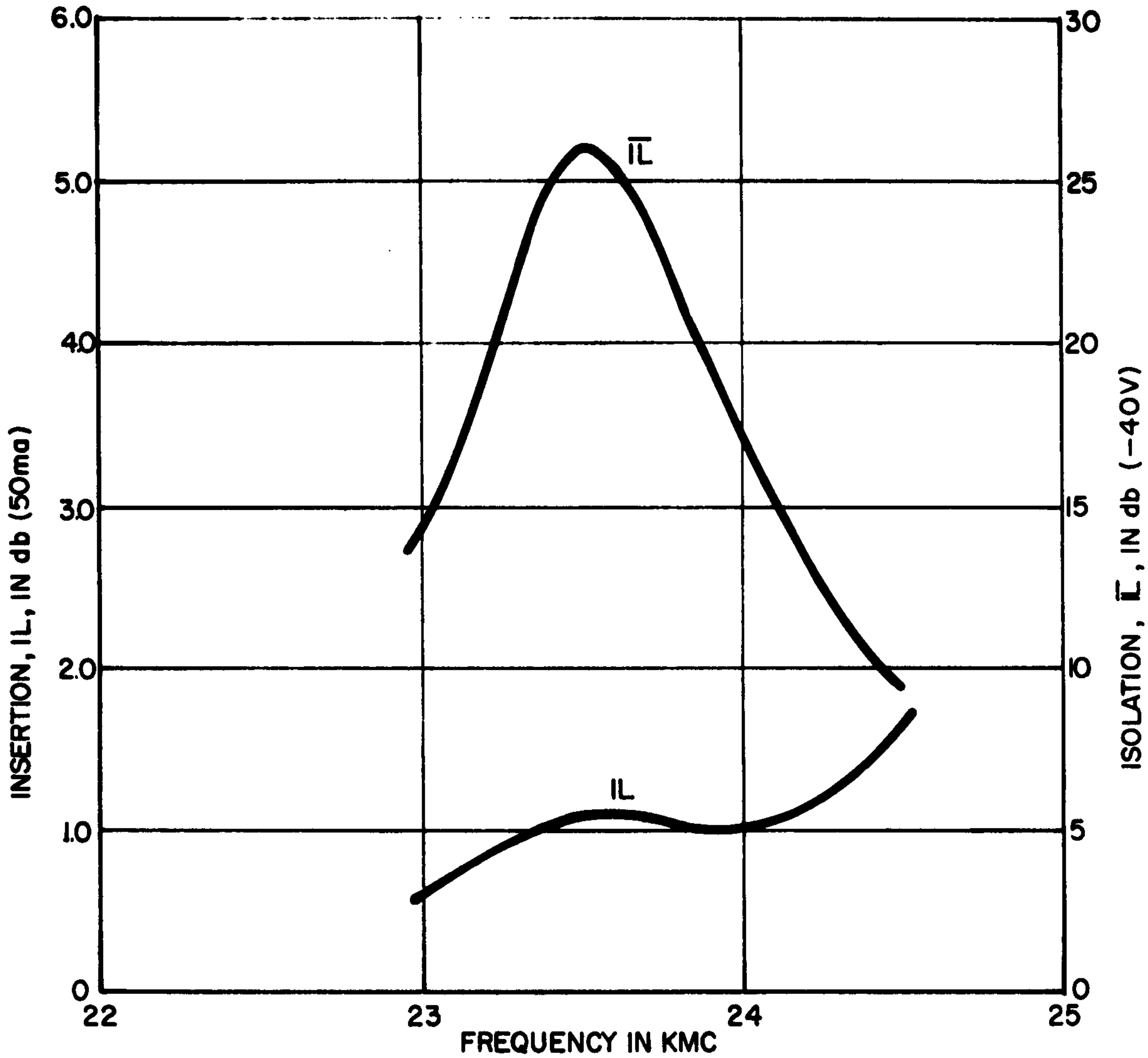


FIGURE (3)
PACKAGED DIODE K-BAND SWITCH PERFORMANCE AT 500 W PEAK INCIDENT POWER.

P_P = 5KW

P_A = 1.5W

PRR = 15 Kc

D_U = .0003

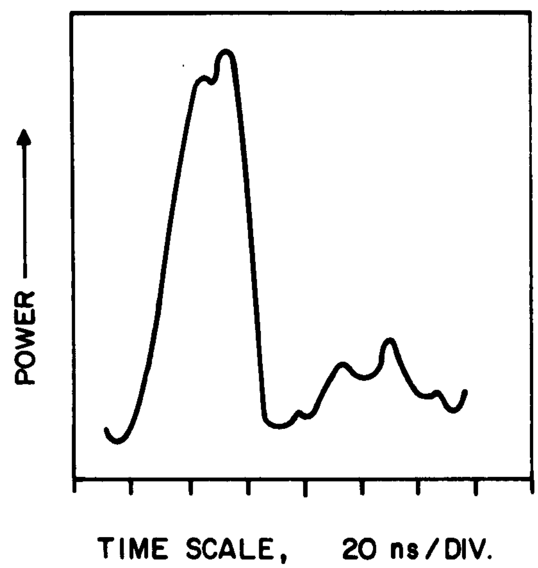


FIGURE 4
DETECTED RF OUTPUT WAVEFORM OF A 6551 MAGNETRON
AS VIEWED ON A 0.5ns RISE TIME OSCILLOSCOPE

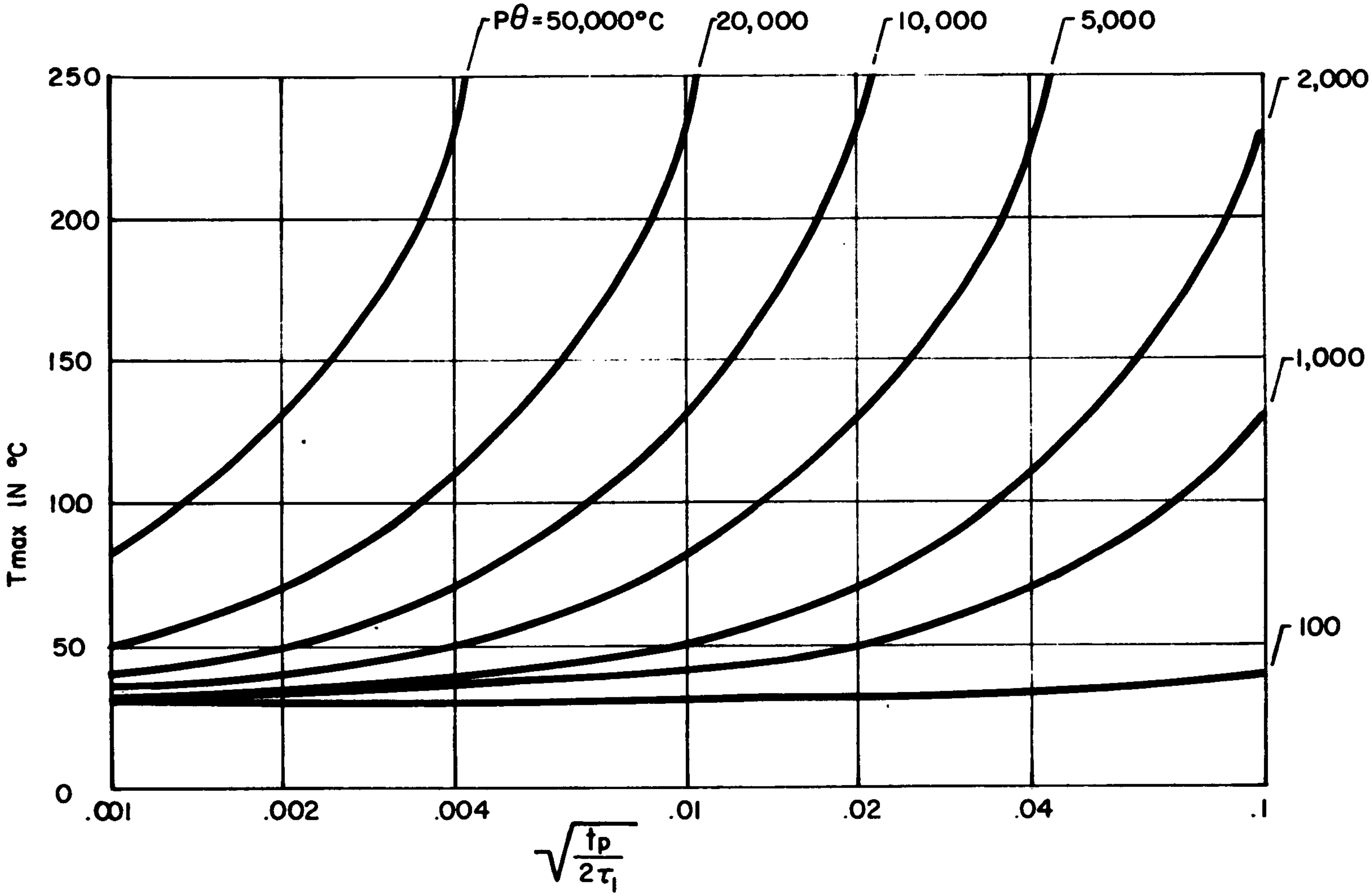


FIGURE 5

PLOT OF THE DIODE JUNCTION TEMPERATE EXPRESSION $T_{max} = T_0 + P\theta\sqrt{\frac{t_p}{2\tau_1}}$

$T_0 = 30°C$

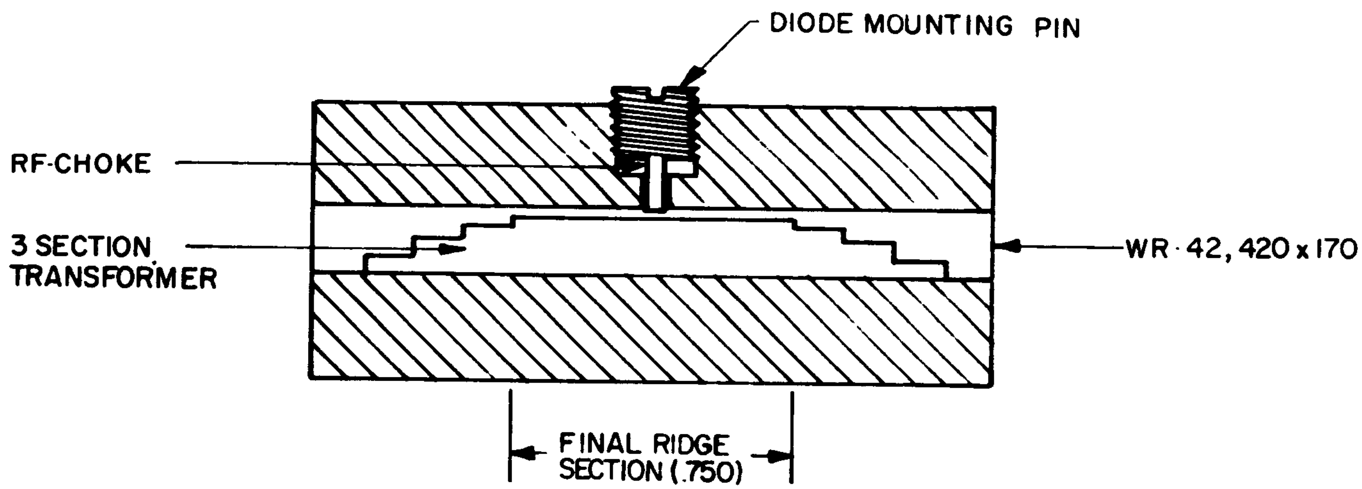


FIGURE 6
SMALL GAP RIDGE WAVEGUIDE SECTION

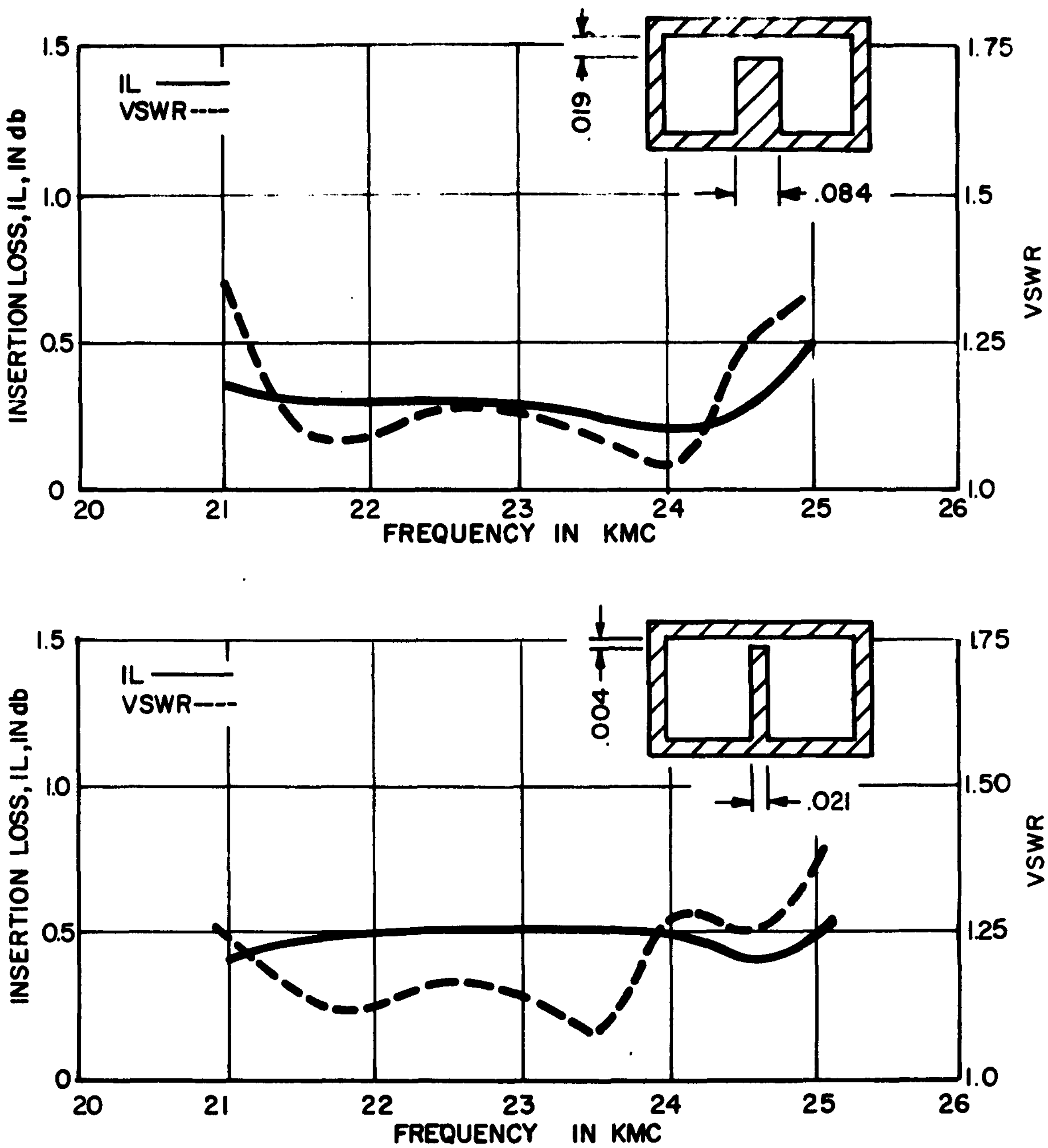


FIGURE 7
PERFORMANCE CHARACTERISTICS OF SEVERAL SMALL GAP RIDGE WAVEGUIDE SECTIONS (WR-42, .420x.170)

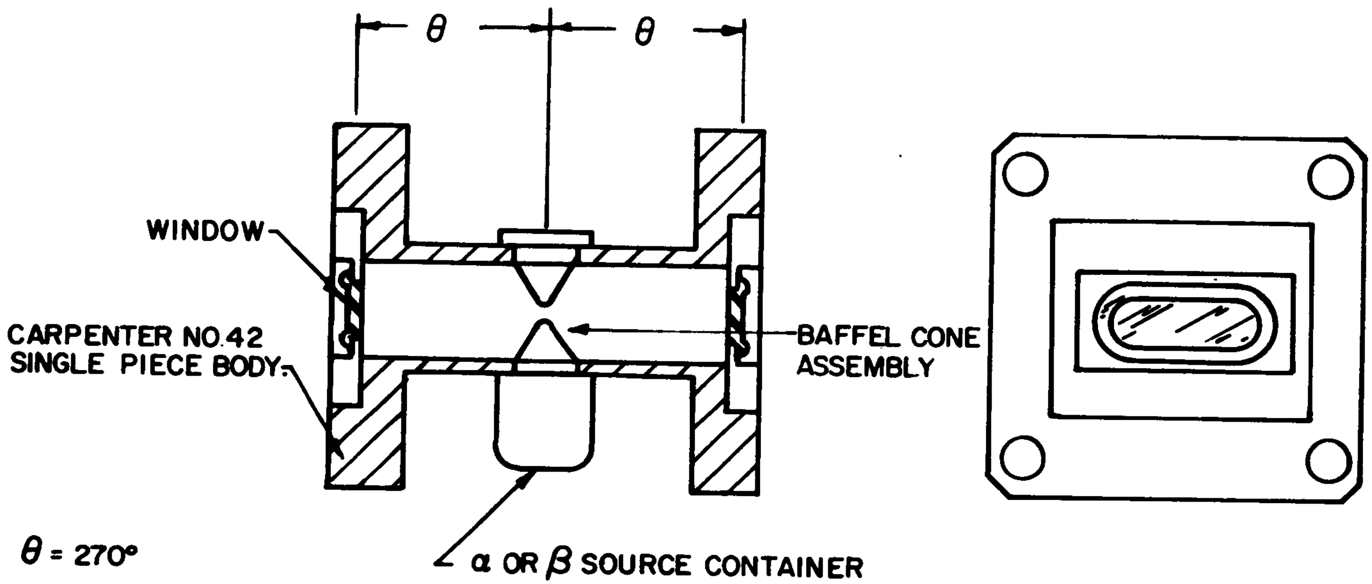


FIGURE 8
LONG LIFE K-BAND TR-TUBE ASSEMBLY

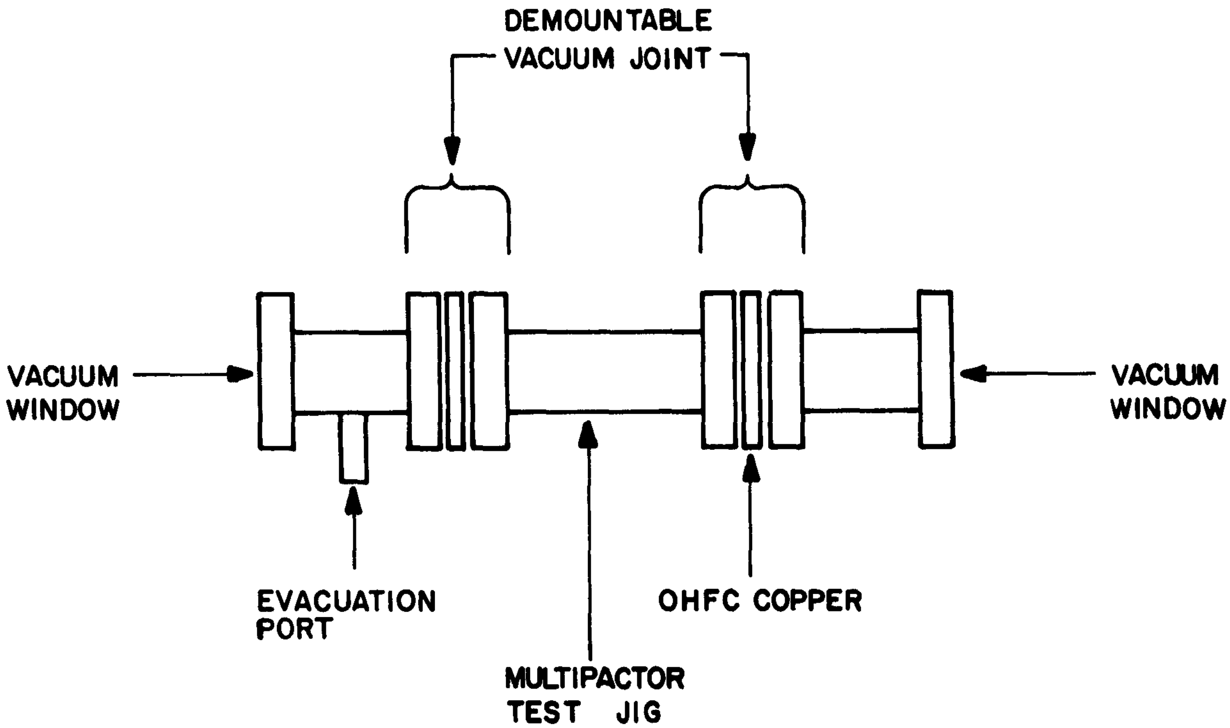
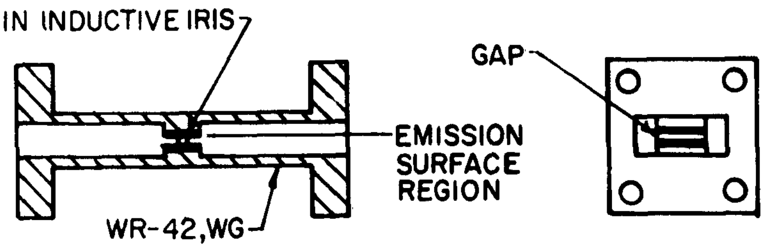
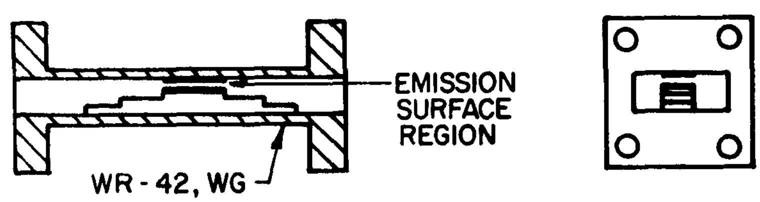


FIGURE 9
DEMOUNTABLE TEST APPARATUS FOR MULTIPACTOR DISCHARGE INVESTIGATION.



(A) PARALLEL RESONANT CIRCUIT



(B) LOW IMPEDANCE RIDGED WAVEGUIDE CIRCUIT

FIGURE 10
MULTIPACTOR DISCHARGE STRUCTURES

APPENDIX A

DR. MEYER GILDEN

Dr. Gilden received a B.S. degree in 1946 and an M.S. degree in 1948 in Electrical Engineering from the Illinois Institute of Technology, and a Ph.D. degree in 1955 from the University of Illinois. At the Institute he was a graduate assistant and instructor in the Electrical Engineering Department; at the University, from 1948 to 1956, he was an instructor and then Assistant Professor in the Electrical Engineering Department and later a member of the staff of the Control System Laboratory. While at the University of Illinois he was also engaged in research in gaseous electronics and radar systems. His thesis was entitled, "Resonance Phenomena at Microwave Frequencies in Gyromagnetic Gaseous Discharges Plasmas".

In 1956, Dr. Gilden left the University to become a member of the Technical Staff of the General Electric Microwave Laboratory in Palo Alto, California, where he was engaged in research and development on microwave components using gaseous discharges, vacuum discharges, and ferrite materials. From August 1959 until he joined Microwave Associates in April 1961 he was a research engineer at Stanford Research Institute and was primarily involved in the design and development of parametric amplifiers and up-converters.

Dr. Gilden is currently a senior engineer in the Electron Tube and Device Division where he is participating in research

and development problems in plasma physics including high power breakdown in waveguide systems and high power duplexers.

Among his publications and oral presentations are:

1. "Guided Wave Propagation Through Ferrites and Electron Gases in Magnetic Fields" co-authored with L. Goldstein, and J. Etter. I.R.E. Convention, 1953 (Convention Record, Part 10 - Microwaves)

2. "Cyclotron Resonance of Electrons in Gaseous Discharge Plasmas" co-authored with L. Goldstein, Gaseous Electronics Conference, 1955.

3. "A Nearly Optimum Wide-band Degenerate Parametric Amplifier" co-authored with G.L. Matthaei, Proceedings of the I.R.E. 49, p. 1833, April 1961.

In addition, he has written numerous company reports on such subjects as:

1. Radar duplexers using vacuum discharges and gas discharges.
2. Phase shifters using gas discharge plasmas.
3. Microwave filters.
4. Microwave instrumentation for shock tubes.
5. Parametric amplifiers.
6. Up-converters.

Dr. Gilden is a member of Sigma Xi, Eta Kappa Nu, the Institute of Radio Engineers (including the IRE Professional Groups on Microwave Theory and Techniques, on Circuit Theory, and Electron Devices), and the American Physical Society.

Charles M. Howell

Mr. Howell is a chemical engineer specializing in semiconductor design and development.

He obtained his B.S. in chemical engineering from Northeastern University in 1954. He is currently working toward his Master's in Business Administration, at the same institution.

Mr. Howell has been with Microwave Associates since early 1958, as a development engineer on silicon junction rectifiers and varactors.

From 1956 to 1958 he was employed as a Junior Development Engineer with Sylvania Electric Products, Inc. in Boston. There he worked on the development of diffused and alloyed silicon power transistors. He had extensive experience with silicon diffusion and contact techniques.

Mr. Howell worked previously as a co-operative student at Raytheon Manufacturing Co. as an engineering assistant. He helped with chemical cleaning and plating problems on magnetrons, and screening of cathode ray picture tubes.

Mr. Howell servedin the Army Signal Corps from 1954 to 1956. He was trained as a high speed radio and radio teletype operator. Most of his time was spent in the maintenance and repair of radio equipment.

Mr. Howell holds professional membership in the ACS, American Institute of Chemical Engineers, Boston Chapter. He has a patent on a chemical dispenser, and has patent applications on a method to improve diffused rectifier reverses by annealing and contacting technique for silicon.

RODNEY J. WHITNEY

Mr. Whitney received his A.E.E. from Lincoln Institute in 1957 and his BBA in Engineering Management from Northeastern University in 1959.

From 1948 to 1952 he served in the U. S. Navy where he completed training in Radar School and served as a radar operator.

From 1952 to 1958 Mr. Whitney was employed by Raytheon as an engineering assistant. His work included testing of magnetrons, amplitrons, TWT's and associated components. He was also involved in the testing of ferrite compositions and fabrication of isolators.

In 1958 he joined the Duplexer Group at Microwave Associates where he was involved in the design and testing of high power gas discharge switching devices.

In October 1962, he became associated with the Solid State Group in the field of semiconductor switching and limiting.

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LONG LIFE K-BAND DUPLEXER

M. E. Hines, R. Tenenholtz

Second Quarterly Technical Report 1 October 1962 - 1 December 1962

38 pp. - Illus. Signal Corps Contract No. DA-36-039-SC-90834

During the second quarterly period of this contract, a specific overall program plan was drawn up to coordinate the various technical activities of concern. In addition, an inspection trip to view an operating ASDE radar was carried out to insure complete compatibility of the duplexer package with that now being used.

In the technical area an improved packaged diode switch was developed and successfully tested at 500 watts peak power. Also, successful initial test results were obtained on several narrow gap ridge waveguide configurations which will be used to mount integrated PN junction structures.

With respect to other areas of concern, a description of preliminary work performed in the ferrite limiter, gas TR and multipactor areas is presented along with accompanying technical discussions.

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